NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

DETERMINING THE OPTIMAL PRESCRIBED LOAD
FOR THE
U. S. MARINE CORPS DIRECT SUPPORT
ARTILLERY BATTERY
USING LINEAR PROGRAMING

by

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June 1987

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable): 54	7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
DETERMINING THE OPTIMAL PRESCRIBED LOAD FOR THE U. S. MARINE CORPS DIRECT SUPPORT ARTILLERY BATTERY USING LINEAR PROGRAMING

12 PERSONAL AUTHOR(S)
DeWeese, Jeffrey L.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	1987 June	50

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Artillery, Artillery Ammunition, Direct Support Artillery Battery, Prescribed Load, Linear Programing

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

In future conflicts, the projected expenditure rates of artillery ammunition greatly exceed the ability of the Marine direct support artillery battery's ammunition transportation assets. It is therefore vital that the artillery battery commander be able to select the most effective mix of ammunition to carry on his organic transportation in a given tactical situation. Linear programing is a tool which the battery commander can use to help solve this important problem. This thesis provides a linear program to assist him in this solution. In addition, with slight modification, this linear program can be of use to commanders at all levels of the Marine artillery organization.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED	
22a NAME OF RESPONSIBLE INDIVIDUAL: Paul M. Carrick	22b TELEPHONE (Include Area Code): (408) 646-2939	22c OFFICE SYMBOL: 54Ca

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

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Determining the Optimal Prescribed Load for the U. S. Marine Corps Direct Support Artillery Battery using Linear Programing

by

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MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1987

ABSTRACT

In future conflicts, the projected expenditure rates of artillery ammunition greatly exceed the ability of the Marine direct support artillery battery's ammunition transportation assets. It is therefore vital that the artillery battery commander be able to select the most effective mix of ammunition to carry on his organic transportation in a given tactical situation. Linear programing is a tool which the battery commander can use to help solve this important problem. This thesis provides a linear program to assist him in this solution. In addition, with slight modification, this linear program can be of use to commanders at all levels of the Marine artillery organization.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

To my wife and children, whose support and encouragement were crucial in making these past eighteen months a success. Thank you, Tricia, Amanda, and Jeffrey.

I. INTRODUCTION

A. BACKGROUND

This thesis deals with proposed future artillery ammunition expenditure rates, artillery ammunition allocations, and the inability of the Marine direct support artillery battery to carry its entire requirement/allocation into combat.

B. OBJECTIVES

The primary objective of this thesis is to develop a decision support model using linear programming which will assist the direct support artillery battery commander in determining what the most effective mix of available ammunition will be, given the tactical situation.

In addition, the secondary objectives of this thesis are to examine;

(1) The characteristics, capabilities, and uses of each type of artillery round provided in the different ammunition allocations and determine a method by which the artillery commander can systematically turn his intuition and military experience into a quantitative measure of effectiveness (MOE), which can be used in the decision support model.

(2) The current ammunition hauling transportation assets of the Marine direct support artillery battery and their use.

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The major thrust of this thesis is the development of a decision support model using linear programming, which the artillery battery commander can use as an aid in determining the most effective mix of ammunition to be carried by the available organic transportation in a given tactical situation. This mix of ammunition is called the battery's prescribed load and it is composed of two standard ammunition allocations. The basic allowance (BA), and the daily supply rate called a 'day of ammunition' (DOA). The ammunition available for the battery's prescribed load is large and bulky, and the battery in most cases will be unable to carry its total allocation on the available transportation in a single lift. Therefore, choices must be made as to what mix of ammunition should be carried and what should be left behind for pickup at a later time based on the reexecution of the decision support model. Additionally, these choices will change as the tactical situation changes and as additions/deletions to the battery's transportation assets occur, due to combat losses.

maintenance, and requirements levied on the battery by the artillery battalion. Thus, there is a requirement for the decision support model to be as simple as possible and easy to use, so that it can be executed as many times as necessary throughout the operation, given the new and changing tactical situation. The decision support model developed in this thesis could be used for any artillery organization with slight modifications, but for the purpose of simplicity during the inital development, this thesis deals strictly with the current Marine direct support artillery battery composed of eight M198 howitzers.

D. METHODOLOGY AND LITERATURE REVIEW

Research data was requested and collected from major Marine Corps offices responsible for artillery, ammunition, ammunition procurement, logistics, and fire support. Data was also collected from Marine Corps orders, tactical manuals, operating manuals, standard operating procedures, studies, and articles. In addition, experts and current members of the Fleet Marine Force artillery organization were interviewed to determine how the decision making process functions and to gain factual information which was not contained in the written material.

E. SUMMARY OF FINDINGS

A simple linear program was developed which can be easily applied by the direct support artillery battery commander using existing commercial software. In addition, software could be developed for use with the battery's organic computer system called the Backup Computer System (BUCS).

F. ORGANIZATION OF STUDY

In the following chapters of this thesis we will first look at the direct support artillery battery's organization, employment, and assets along with the types of artillery ammunition most commonly used in support of the maneuver force. In Chapter III, we will take a closer look at linear programming and develop the general version of the actual decision support model. Chapter IV then applies the decision support model developed in the previous chapter to a specific scenario as an example of how the commander would use the model in the determination of the most effective prescribed load for the given scenario. Chapter V then offers some conclusions and specific recommendations for further study.

II. ARTILLERY ORGANIZATION AND PROJECTILES

A. INTRODUCTION

To assist artillery commanders to properly solve the problem of making the most effective and economical choices of ammunition to carry on-board organic transportation in a given tactical situation, a closer look at two major components of the problem is required.

The first component requiring closer examination is the battery itself. We will review its mission, organization/structure, and the transportation assets, highlighting those assets which will be used in the transportation of ammunition.

The second component is the ammunition used by the direct support artillery battery in the accomplishment of its mission. In this portion we review artillery ammunition in general and give a detailed description of each type of artillery round commonly used by the direct support artillery battery.

B. MARINE DIRECT SUPPORT ARTILLERY BATTERY

1. Mission

In general, the mission of the field artillery is threefold:

(1) To provide close and continuous fire support,

(2) To give depth to combat, and

(3) To achieve and maintain fire superiority.

The primary mission of the Marine artillery battery is derived from the mission of its parent artillery battalion. For the purposes of this paper, we will be dealing with the Marine direct support artillery battalion and its assigned direct support mission. Additionally, in the direct support role, the mission of the artillery battery is the same, whether it is part of its parent battalion or it is independently deployed as part of a Marine Amphibious Unit.

The direct support artillery mission requires the battery to assign forward observers to, and establish a liaison section with, the supported infantry battalion. The artillery assigned the direct support mission, through its parent battalion, is thus immediately responsive to the fire support needs of a specific maneuver battalion. The direct support unit must position itself to provide close continuous fires to the supported maneuver force and must coordinate its planned fires, both scheduled and

on call, with the battle plans of the maneuver commander. The zone of fire of the direct support unit is the zone of action of the supported unit. The direct support unit responds to calls for fire, in priority, from forward observers with the supported unit, from other observers, and from the force artillery headquarters. The direct support mission is the most decentralized of all tactical missions. [Ref. 1: p. 17]

2. Organization/Structure

For the purposes of this paper and the development of the decision support model, we will be dealing strictly with the direct support artillery battery, which is equipped with eight M198, 155mm towed howitzers.

The direct support battery is composed of 186 marines and is divided into a battery headquarters and two, four-howitzer firing platoons (see Figure 2.1). The battery headquarters is composed of a headquarters section, a communications section, a maintenance section, a medical section, and a liaison section. The two four-howitzer firing platoons are composed of a platoon headquarters, a fire direction center, and four howitzer sections. Additionally, each firing platoon is augmented with assets from the battery communications and medical sections.

The split battery concept of operations allows for greater survivability through dispersion and facilitates simultaneous engagement of multiple targets and continuous coverage during displacements, since each platoon is capable of autonomous operations. However, the preferred method of engagement is to mass the battery's fire on a single target. Command and control is extended to the firing platoons through their organic fire direction center, firing platoon commander, and intrabattery communications.

When deployed (see Figure 2.2), the firing platoons of the battery have a frontage of approximately 400 meters and a depth of 200 meters. Additionally, the platoons are separated from each other by between 400 and 1600 meters. Limited logistical support is provided from the battery headquarters, whose location may be separate or collocated with one of the firing platoons. [Ref. 2: p. J-1]

3. Battery Transportation Assets

The direct support artillery battery possesses transportation assets as outlined in Table 1.

Those transportation assets of particular concern in deriving a decision support model for the solution of this ammunition choice problem are the twenty M813, five ton trucks and the ten, M105A1, one and one half ton trailers. The eleven,

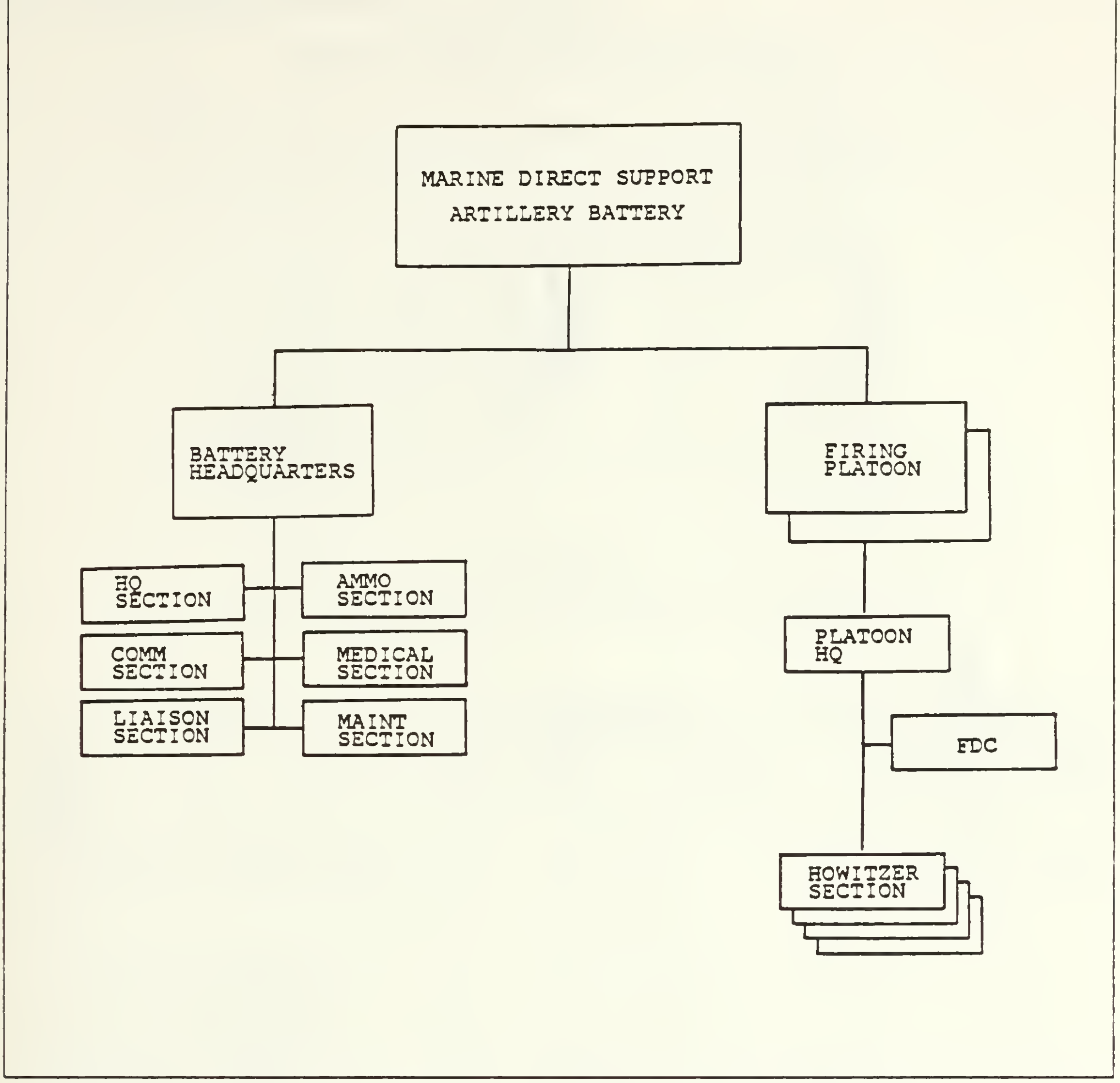


Figure 2.1 Marine Direct Support Artillery Battery.

M998, one and one quarter ton trucks are used as command and radio vehicles, and they are generally not available for the transportation of artillery ammunition. A typical distribution and use of these potential ammunition hauling transportation assets is outlined in Table 2. Additionally, the important characteristics of each of these vehicles are listed in Table 3.

Data in the tables reveals that there is not a great deal of ammunition hauling capability contained within the assets of the direct support artillery battery, especially when one considers the projected expenditure rates of between 71 and 550 rounds per

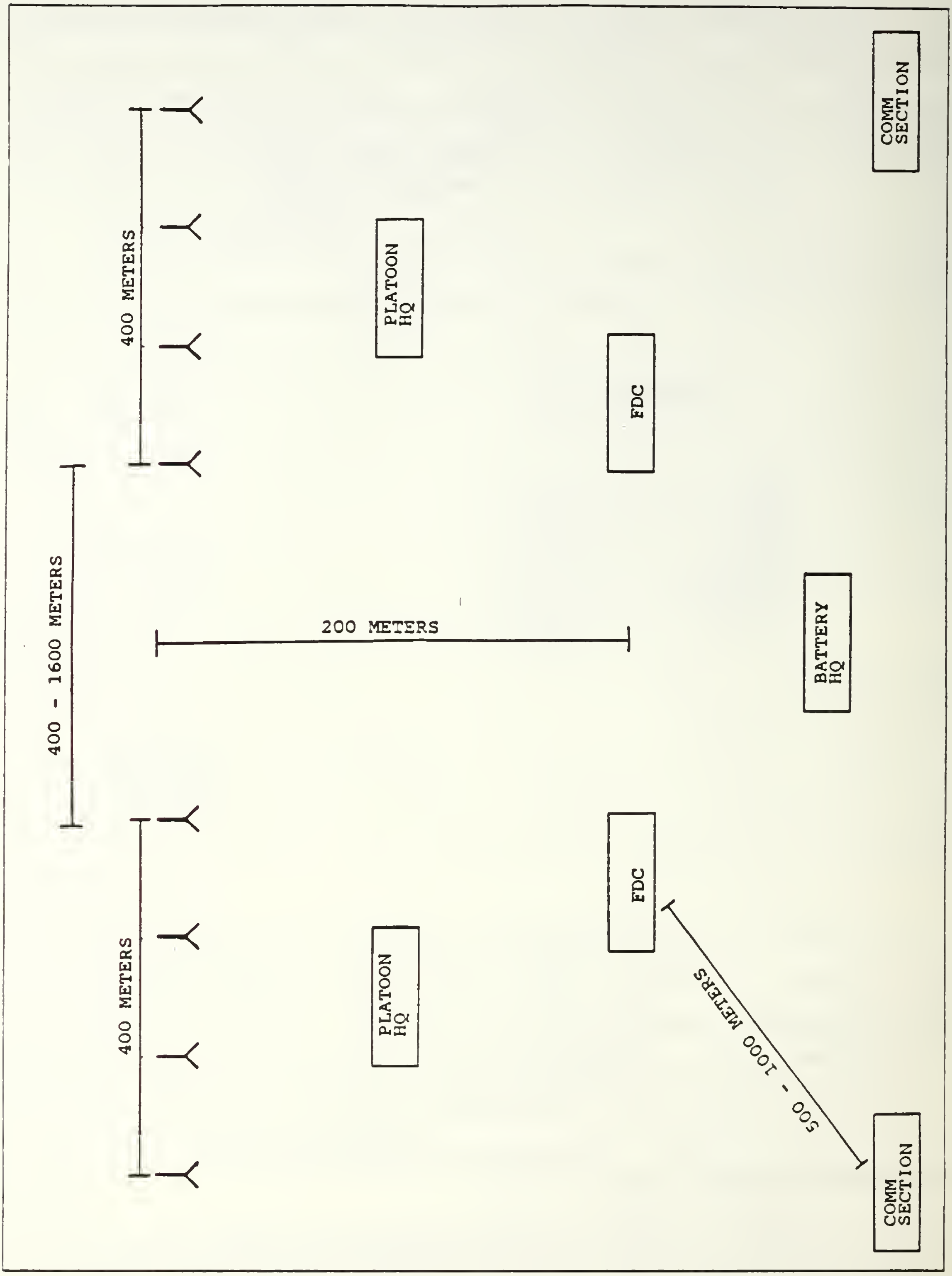


Figure 2.2 General Deployment of Direct Support Battery.

TABLE 1

BATTERY TRANSPORTATION ASSETS

VEHICLE TYPE	QUANTITY
Trailer, 1.5 Ton, M105A1	10
Trailer, Water, M149A2	2
Truck, 1.25 Ton, M998	11
Truck, 5 Ton, M813	20

TABLE 2

USES OF BATTERY TRANSPORTATION ASSETS

USE	QUANTITY M813	QUANTITY M105A1	NUMBER OF ROUNDS CARRIED EA.	NUMBER OF ROUNDS CARRIED TOT.
Howitzer Prime Mover	8		54	432
FDC	2			
Platoon Supply	2			
Battery Supply	1	1		
Battery Maint.	1	1		
Platoon Comm.		2		
Battalion Requirement	3	3		
Battery Ammunition	3	3	96	288
TOTAL	20	10		720

howitzer per day for future conflicts, (see Appendix A). This problem becomes particularly acute when assets must be given up to battalion requirements or they are completely left behind due to amphibious shipping limitations. Additionally, maintenance takes its own toll on these valuable assets. Thus the loss of these trucks to

TABLE 3

CHARACTERISTICS AND CAPABILITIES OF AMMUNITION HAULERS

VEHICLE	CARGO AREA		MAX. PAYLOAD	MAX. TOWED LOAD
	FT^2	FT^3	(lbs)	(lbs)
M813	98	550	10,000	15,000
M105A1	56	211	3,000	NA

whatever means, and the "shortage of ammunition vehicles will prove to be the Achilles' heel of the battery" [Ref. 3].

Recent U.S. Army field experience under expected combat conditions has shown that:

> The lack of battery ammunition trucks proved particularly problematic during displacements. Because the battery had no on-site ammunition trucks, most incoming rounds were downloaded to the ground and distributed piecemeal to the howitzers as needed. When ordered to displace, battery personnel loaded all the rounds they could on prime movers and left the remainder stockpiled for later pickup. If the battery had to displace hastily, crews simply abandoned stocks on the ground; howitzer prime movers departed with what they had on board at the moment.
>
> The lack of battery ammunition trucks degraded the combat effectiveness of the firing battery and, in the long run, placed a tremendous burden on the supply system. The battalion's leaders did consider ... pressing into service the battery's maintenance and supply trucks to move ammunition. However, the typical load of basic issue items completely filled the trucks. Use of the maintenance and supply trucks, although feasible in an extreme emergency, would result in the loss of their cargo. What's more, there would be little time in an emergency situation to load these trucks with ammunition. [Ref. 4: pp. 28-29]

From the above account, it is obvious that to be successful in his mission, a commander must insure that his available ammunition carrying capacity is constantly loaded with a mix of ammunition, which will best meet the needs of the tactical situation. Let's now take a look at these different types of ammunition and their uses.

C. 155MM ARTILLERY AMMUNITION

1. General

The 155mm artillery ammunition used in the direct support artillery battery is classified as separate loading ammunition. This means the ammunition has four separate components which are issued individually. These components are the fuze, projectile, propellant, and the primer. At the howitzer, the fuze is mated with the projectile and this assembly is then loaded into the howitzer. The proper amount of propellant is then loaded into the howitzer and the breech is closed. Finally, the primer is inserted and the howitzer is ready for firing.

Each component of the 155mm separate loading artillery ammunition, except for the primer, comes in several varieties for different uses and effects. In addition to the following descriptions each component and its corresponding logistics data is listed in Table 4. The definitions of different artillery ammunition allocations and terms are contained in Appendix B.

2. Fuzes

The purpose of the fuze is to either detonate the projectile or expel the contents of the projectile at the proper time.

The most commonly used are the impact fuzes, M557, M572, or M739. These fuzes are used to detonate the projectile when it impacts with the target. These three fuzes function similarly and have two settings. The first is the superquick setting designed to cause the projectile to burst at the instant of impact allowing most of the explosive effect to take place above ground. The second setting is the delay setting causing a .05 second delay in detonation which allows the projectile to penetrate the target, such as a bunker prior to detonation.

The other type of impact fuze is the M78 concrete piercing fuze. This fuze is used for the destruction of hardened fortifications and is seldom used because artillery is an area weapon rather than a point destruction weapon.

The next major group of fuzes are the mechanical time and proximity fuzes. These fuzes cause the projectile to detonate above the target.

The mechanical time fuzes, M501A1, M564, M577, and M582, in addition to their mechanical time function, have a superquick function allowing them to detonate the projectile if it impacts prior to the time setting on the fuze. The M501A1 fuze is used only on smoke projectiles. The M564 and M582 fuzes are used on high explosive and white phosphorous projectiles. Finally, the M577 fuze is used on the base ejecting

TABLE 4

155MM ARTILLERY AMMUNITION LOGISTICS DATA

ITEM	UNIT PACK	WEIGHT EACH (lbs)	CUBE EACH (FT^3)	TOTAL WEIGHT (lbs)	TOTAL CUBE (FT^3)
FUZES:					
M557	16	3.361	.073	53.8	1.16
M78	16	4.119	.064	65.9	1.02
M501A1	16	3.450	.046	55.2	.74
M564	16	3.450	.073	55.2	1.16
M577	16	3.252	.067	52.0	1.07
M728	16	3.938	.081	63.0	1.29
M732A1	16	3.867	.077	61.9	1.23
PROJECTILES:					
HE	8	92.8	.829	742	6.63
HE RAP	8	90.9	1.87	727	14.96
ICM	8	100.5	.856	804	6.85
DPICM	8	109.2	1.213	874	9.70
WP	8	103.1	.829	825	6.63
SMK	8	90.9	.834	727	6.67
ILLUM	8	97.8	.856	782	6.85
PROPELLANTS:					
M3A1	48	19.0	1.086	910	52.1
M4A2	50	30.5	.757	1525	37.8
M119A1	50	41.3	2.000	2065	100.0
M203	18	120.0	3.000	2160	54.0

NOTE: (1) Weights and volumes contain shipping containers
(2) Differences due to rounding

type of projectiles such as the improved conventional munitions and the illumination projectile.

The proximity fuzes, M728 and M732A1, are used on high explosive and gas projectiles to cause the projectile to detonate seven meters above the target. These fuzes also point detonate if they impact prior to the time setting.

3. Projectiles

In this section and in the development of the decision support model, we will only include the projectiles most commonly used by the direct support artillery battery. This is because projectiles such as the Copperhead, gas projectiles, and the Family of Scatterable Mines projectiles are in limited supply and will probably be fired by a specific battery, for a specific mission under the direct control of the maneuver commander.

The projectiles commonly used by the direct support artillery battery are the High Explosive (HE) projectile (M107), the White Phosphorous (WP) projectile (M110A1), the Improved Conventional Munitions (ICM or DPICM) projectiles (M449A1 or M483A1), the High Explosive Rocket Assisted (HE RAP) projectile (M549A1), the Illumination (ILLUM) projectile (M485), and the White Smoke (HC SMK) projectile (M116).

The High Explosive projectile can use an impact, mechanical time, or proximity fuze depending on availability and the required effects on the target. This type of projectile is used for blast and fragmentation effects on targets of personnel, equipment, material, and fortifications.

The High Explosive Rocket Assisted projectile uses either an impact or a proximity fuze. Its uses are similar to the High Explosive projectile, however it has a greatly extended range, 30,000 meters with the M203 propellant vice the 18,000 meters for the High Explosive projectile using the M119A1 propellant.

The Improved Conventional Munitions projectiles use mechanical time fuzes to expel their submunitions over the target area. The M449A1 projectile is used against personnel targets and has proven to be more effective at producing casualties in open terrain than the HE projectile with a proximity fuze. The M483A1 projectile is called the Dual Purpose Improved Conventional Munitions projectile because its submunitions contain a shaped charge which burns a hole through 2.75 inches of homogenous armor plate in addition to its fragmentation effects. The M483A1 dual purpose projectile has proven to be very effective against all types of personnel, equipment, and vehicle targets including armor in open terrain. The M483A1 dual purpose projectile is the preferred munition in many cases.

The White Phosphorous projectile uses impact and mechanical time fuzes and is used to provide spotting and screening smoke. It also has a slight incendiary effect.

The White Smoke projectile uses a mechanical time base ejecting fuze and is used to provide screening smoke.

The Illumination projectile uses a mechanical time base ejecting fuze and is used to provide battlefield illumination and as a position marker.

4. **Propellants**

There are four types of propellants used by the direct support artillery battery. They are the M3A1 Green Bag propellant for use out to 9800 meters, the M4A2 White Bag propellant, which is the most common, for use out to 14,700 meters, the M119A1

propellant for long range, out to 18,000 meters, for use with all projectiles except the M116 Smoke projectile, and the M203 propellant for use only with the M549A1 rocket assisted projectile to achieve the maximum 30,000 meter range.

III. MODEL DEVELOPMENT

A. INTRODUCTION

The decision support model developed in this chapter. uses a technique called linear programming. Linear programming is one of the most widely used methods for problem solving and has been used extensively by the military, since its development during World War II, in areas such as logistics, transportation problems, and procurement problems. It is a mathematical technique for optimally allocating scarce resources to achieve an objective, such as the problem of determining the most effective mix of 155mm artillery ammunition and transporting it on the battery's organic transportation. "Linear programming involves the description of a real world decision situation as a mathematical model that consists of a linear objective function and linear resource constraints." [Ref. 5: pp. 25-26]

B. ASSUMPTIONS

In conducting the analysis and developing the decision support model, several assumptions were required, and are listed below:

(1) In addition to the howitzer prime movers, the battery will only have three additional M813 trucks with M105A1 trailers for the transportation of ammunition. This is due to other commitments previously outlined in Chapter II. This assumption is represented in the constraints of the model and can be changed easily if it is not the case for a particular user of the model.

(2) The only types of 155mm artillery ammunition considered in the development of this decision support model are those that are most commonly used by the direct support artillery battery. As stated earlier, this is because projectiles such as the copperhead, gas projectiles, and the Family of Scatterable Mines projectiles are in limited supply and will probably be fired by a specific battery, for a specific mission under the direct control of the maneuver commander.

(3) The battery is not concerned with the pickup and transportation of the ammunition from the Ammunition Supply Point (ASP). This is done by the higher headquarters and is either delivered to the battery while it is in position or at a predetermined location on its route between positions.

C. MODEL FORMULATION

1. Introduction

The basic problem concerns the optimum allocation of scarce resources. In this particular case, the battery commander's task is to achieve the best mix of ammunition, given the limited resources of ammunition availability and transportation. The desired outcome is expressed as the maximization of the effectiveness or desireability given a specific tactical situation.

Once the problem has been identified, and the goals of the battery commander established, the next step is the formulation of a mathematical model. This entails three major steps:

(1) The identification of decision variables,

(2) The development of an objective function that is a linear relationship of the solution variables, and

(3) The determination of system constraints which are also linear relationships of the decision variables, that reflect the resource limitations. [Ref. 5: p. 26]

2. Decision Variables

In this problem the decision variables represent the quantities of the different types of artillery ammunition that are normally fired by the direct support artillery battery. These variables are listed in Table 5 and they are expressed as the number of complete rounds of the specific type.

3. Objective Function

The objective of this problem is to maximize the total effectiveness of the artillery ammunition mix carried on the direct support artillery battery's organic transportation. The total effectiveness of the ammunition mix is determined by adding together the effectiveness of each type of projectile contained in the mix. Therefore, the total effectiveness of the mix, depicted by the variable Z, can be determined from the following linear Equation 3.1;

$$\text{Max } Z = w_1 x_1 + w_2 x_2 + w_3 x_3 + w_4 x_4 + w_5 x_5 + w_6 x_6 + w_7 x_7 + w_8 x_8 \qquad \text{(eqn 3.1)}$$

where w_i is a weighting factor or measure of the projectile's effectiveness/desireability as determined by one of two ways.

(1) By higher headquarters and passed down in the form of what percent of the prescribed load is made up of each type of projectile. See Appendix C for examples of recommended prescribed loads.

TABLE 5

DECISION VARIABLES

VARIABLE	PROJECTILE
x_1	HE (PD)
x_2	HE (VT)
x_3	HE (RAP)
x_4	ICM
x_5	DPICM
x_6	WP
x_7	ILLUM
x_8	HC SMOKE

(2) By the supported maneuver commander with the assistance of the artillery commander, taking into consideration the factors of mission, enemy, terrain weather, and troops, (METT), and then applying a simple weighting system derived from a pairwise comparison, (see Appendix D), which produces weighting factors such as those outlined in Table 6.

TABLE 6

PROJECTILE WEIGHTING SYSTEM

COEFFICIENT	WEIGHTING FACTOR
w_1	.12
w_2	.19
w_3	.08
w_4	.19
w_5	.25
w_6	.07
w_7	.04
w_8	.06

It is important to note, that if we had a known target array and the maneuver commander's target priorities, we would be able to determine our exact artillery ammunition needs. However, lacking this type of perfect information, it is necessary for us to use some other method. Thus, because of this lack of perfect information and the constantly changing tactical situation, the METT technique is, by far, the preferred method of assigning projectile weighting factors.

When using the METT technique, the mission will greatly affect the prescribed load configuration. The maneuver commander's guidance for fire support and target effects will likely be a principal determinant of the projectile weighting factors. The enemy's known or expected capabilities, forces, and types of equipment will be the other principal determinants in deciding each of the projectile weighting factors. The terrain/weather in which the artillery unit will be employed and the terrain/weather in which the target effects are to be achieved will also help to determine the weighting factor applied to each type of projectile. Finally, the troops element considers the ability of the battery's personnel and equipment to handle, transport, and shoot the prescribed load.

In assisting the maneuver commander in the evaluation of METT and the determination of the artillery's prescribed load, the artillery commander should ask himself the following questions, which for the most part were taken from Reference 6, pages 12 through 14.

- What is the supported unit's mission?
- Is the supported unit attacking or defending?
- Is the supported unit the main effort or a supporting effort?
- How is the supported unit equipped; is it very light, or very heavy, requiring more or less antiarmor support against some threats?
- What are the supported commander's fire support preferences?
- Does he expect artillery or mortars to provide the bulk of his illumination and smoke?
- Does he rely on the artillery to disrupt and kill?
- Does he envision artillery playing a major role in the close battle, counterfire, or interdiction?
- What is the anticipated threat?
- What is the size of the threat unit, and how is it equipped?
- Is it attacking or defending?

- What elements within the threat doctrinal target array are important for achieving threat objectives?
- What part is the field artillery expected to play in denying the employment of these elements?
- What are the characteristics of the terrain in the area of operations?
- Is the ground soft (where HE impact is not very effective) or hard (where HE impact is very effective)?
- Does the terrain cause targets to group together (Korean valleys) or spread out (Sinai desert)?
- What will be the force artillery support?
- Does the force artillery assume responsibility for certain targets or target categories?
- Are the force artillery weapons common or unique: i.e., if prescribed load computations prove to be wrong, can force artillery help out with its prescribed load?
- How much close air support will be available to the maneuver commander and what type will it be?
- How much naval gunfire support will be available to the maneuver commander and what type will it be?
- Who has the influence in determining a unit's prescribed load?
- Has higher headquarters allowed the field artillery commander to ask questions and adjust his prescribed load, or must he carry what he is told to carry?
- What munitions are available for the prescribed load and resupply?
- Are there sufficient theater stocks of these munitions for commitment to the prescribed load?
- What is the current conventional hauling capacity of the unit?
- Is there an overload policy, if so, what is it and what impact does it have on the unit's prescribed load?
- What are the number of vehicles, by type, available to haul the prescribed load?
- How long must a unit plan to fight with what it has on hand?
- When can a unit realistically expect to be resupplied?
- What will be the munitions mix of the resupply?
- How do the answers to these questions affect the support a unit can provide to the maneuver commander?

4. System Constraints

In this ammunition mix problem, the major constraint is the limited amount of organic ammunition hauling capacity available to the direct support artillery battery.

Other constraints of the system are the availability of the different types of projectiles and the nonnegativity/tactical flexibility considerations of having zero or greater of each type of projectile. The linear constraint equations which apply to this ammunition mix problem are as follows:

(1) Transportation constraint:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 = 720 \qquad \text{(eqn 3.2)}$$

This represents the amount of organic transportation available to carry artillery ammunition . It is expressed as the number of complete rounds the direct support battery can carry given the situation, and in this case it is derived from the information in Table 2 of Chapter II.

(2) Ammunition availability constraints:

$$\begin{aligned} x_1 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_2 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_3 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_4 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_5 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_6 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_7 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_8 &\leq \text{(AVAILABLE AMMUNITION)} \end{aligned} \qquad \text{(eqn 3.3)}$$

These constraints represent the amount of artillery ammunition available for the operation, by projectile type. The value is determined, by the number of rounds currently on hand by type, plus the established Available Supply Rate (ASR), which has been passed to the artillery commander during the planning phase of the operation.

(3) Nonnegativity/tactical flexibility constraints:

$$x_1 , x_2 , x_3 , x_4 , x_5 , x_6 , x_7 , x_8 \geq 0 \qquad \text{(eqn 3.4)}$$

These constraints prevent the decision variables from taking on a negative value. However, if a certain quantity of a particular projectile is required, then that quantity should replace the zero in the constraint for that projectile.

5. **Summary**

The complete decision support model using linear programming looks like the following:

(1) Objective function:

$$\text{Max } Z = w_1 x_1 + w_2 x_2 + w_3 x_3 + w_4 x_4 + w_5 x_5 + w_6 x_6 + w_7 x_7 + w_8 x_8 \qquad \text{(eqn 3.1)}$$

(2) Subject to the following constraints:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 = 720 \qquad \text{(eqn 3.2)}$$

$$\begin{aligned} x_1 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_2 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_3 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_4 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_5 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_6 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_7 &\leq \text{(AVAILABLE AMMUNITION)} \\ x_8 &\leq \text{(AVAILABLE AMMUNITION)} \end{aligned} \qquad \text{(eqn 3.3)}$$

$$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \geq 0 \qquad \text{(eqn 3.4)}$$

Thus, by solving the model for the optimum values of the decision variables, x_1 through x_8, the total effectiveness of the ammunition mix, Z, will be maximized.

IV. APPLICATION OF THE DECISION SUPPORT MODEL

A. INTRODUCTION

The purpose of this chapter is to provide an example for the reader of how the decision support model developed in Chapter III, would be applied by the artillery commander in a given scenario. The scenario used in this example is based on the deliberate attack phase of the combined arms exercises (CAXs) conducted at the Marine Corps Air Ground Combat Center, Twentynine Palms, California. During these combined arms exercises, Marine units conduct a variety of missions against enemy forces that change in strength and mixture of armor/infantry. The deliberate attack scenario outlined below is an adaptation of a similar scenario given in Reference 1 on pages 7 and 8.

B. SCENARIO

In the deliberate attack phase, (see Figure 4.1 and refer to Appendix E for a listing of the symbols), the Marine Battalion Landing Team (BLT), conducts a deliberate attack with companies A and B abreast. Company C is the BLT reserve. All three companies have been augmented with assets from the Weapons company and the Combat Engineer platoon. Additionally, because Company A is the main effort, the BLT's tank and amphibious tractor platoons have been attached to it and Company A will receive the priority of fires from the artillery battery. Company B will conduct a supporting attack and have the priority of fires from the battalion's 81mm mortars and the direct support naval gunfire ship.

The enemy force is composed of a reinforced motorized rifle company. The enemy is defending in zone with a squad sized patrol forward of its positions. The maneuver commander has assigned the following priorities to potential targets as outlined in Table 7. These target priorities will be used to determine the sequence of attack for otherwise simultaneous missions. In addition, they will assist the artillery commander as one component in his subjective determination of the projectile weighting factors using pairwise comparisons.

The terrain that the deliberate attack will be conducted over is a large desert valley with sparse vegetation and rocky soil. The enemy is located in defensive positions on two small pieces of high ground located in the center of the valley.

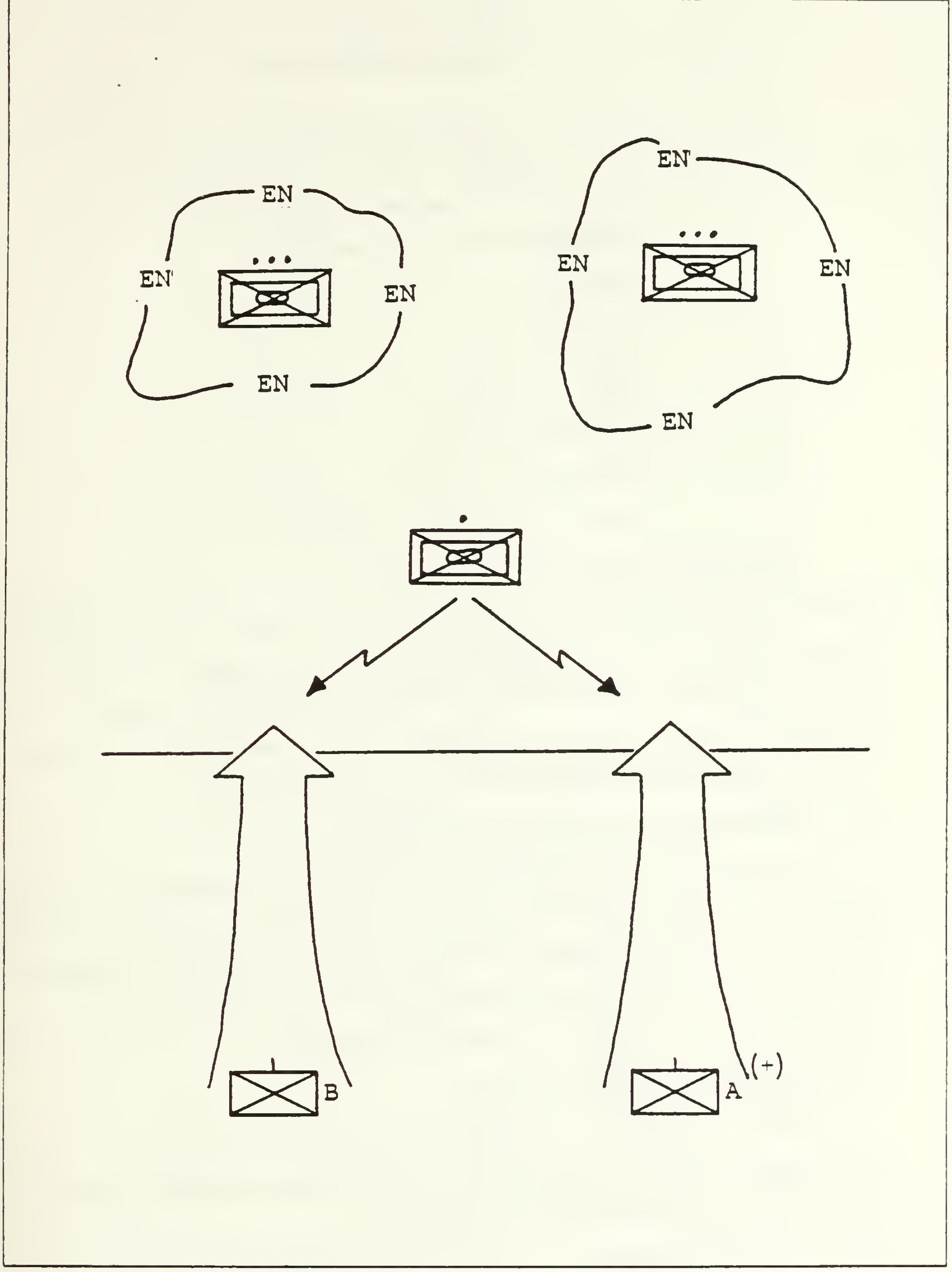


Figure 4.1 Deliberate Attack Scenario.

TABLE 7

TARGET PRIORITIES

TARGET TYPE	PRIORITY
Preparation Fires	1
Tanks	2
Infantry	3
Artillery	4
Air Defense	5
Command Post	6
Logistics Area	7

The maneuver commander has determined that the attack will kick-off at first light and that the artillery battery must be able to provide screening smoke and some spotting smoke for four scheduled sorties of close air support. A limited preparation will be fired prior to the attack and a special ammunition allowance will be made available for this purpose. The available artillery ammunition for the direct support artillery battery is listed below in Table 8.

C. WEIGHTING FACTOR DEVELOPMENT

The artillery battery commander, knowing the tactical situation, the maneuver commander's guidance, and the answers to the questions outlined in Chapter III, develops the decision variable weighting factors as described in Appendix D and outlined below in Table 9. This weighting factor is then used in the decision support model as outlined in Chapter III, Section C, Subsection 3.

D. DECISION SUPPORT MODEL

Given the scenario, the weighting factors developed above, and the use of the transportation assets as outlined in Table 2 of Chapter II, the decision support model's objective function and constraints are as follows;

(1) Objective function:

$$\text{Max } Z = .12x_1 + .19x_2 + .08x_3 + .19x_4 + .25x_5 + .07x_6 + .04x_7 + .06x_8 \qquad \text{(eqn 4.1)}$$

TABLE 8

ARTILLERY AMMUNITION AVAILABLE

AMMO TYPE	QUANTITY AVAILABLE
HE (PD)	248
HE (VT)	144
HE (RAP)	120
ICM	240
DPICM	168
WP	96
ILLUM	64
HC SMOKE	88

TABLE 9

DECISION VARIABLE WEIGHTING FACTORS

COEFFICIENT	WEIGHTING FACTOR
w_1	.12
w_2	.19
w_3	.08
w_4	.19
w_5	.25
w_6	.07
w_7	.04
w_8	.06

(2) Subject to the following constraints:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 = 720 \qquad \text{(eqn 4.2)}$$

$$
\begin{aligned}
x_1 &\leq 248 \\
x_2 &\leq 144 \\
x_3 &\leq 120 \\
x_4 &\leq 240 \\
x_5 &\leq 168 \\
x_6 &\leq 96 \\
x_7 &\leq 64 \\
x_8 &\leq 88
\end{aligned}
\qquad \text{(eqn 4.3)}
$$

$$
\begin{aligned}
x_1 &\geq 0 \\
x_2 &\geq 0 \\
x_3 &\geq 0 \\
x_4 &\geq 0 \\
x_5 &\geq 0 \\
x_6 &\geq 16 \\
x_7 &\geq 0 \\
x_8 &\geq 16
\end{aligned}
\qquad \text{(eqn 4.4)}
$$

Note, that the values for x_6 and x_8 in Equation 4.4, must be greater that or equal to sixteen vice zero. This is done to insure that there will be a minimum number of WP and HC SMOKE rounds available for the planned spotting and smoke missions.

E. RESULTS

Once the decision support model has been completed, it is then executed by any one of a number of software packages that are currently available or that can be developed for the battery's organic computer systems. The resulting output is the optimal number of rounds of each type that the direct support battery should carry on its organic transportation. A sample of this output is contained in Appendix F and the values for the decision variables are also contained in Table 10.

Finally, lets take a look at the additional information provided in the computer printout contained in Appendix F. This information, listed in the results and the sensitivity analysis portions, such as slack or surplus, shadow prices, and upper lower limits, can be very useful to the artillery commander.

The slack or surplus column lets the commander know how many rounds of each type of ammunition are left over from his original ammunition allocation for the operation after he has loaded the optimal solution. These amounts must then be delivered to his unit at a later time. Additionally, those types of ammunition which have zero slack or surplus have a corresponding shadow price. This shadow price tells

the commander how much the prescribed load's effectiveness will be improved or degraded if he obtained or lost one round of this type of ammunition keeping everything else the same. In other words, this is what one additional round of this type would be worth to the artillery commander, at the margin, in terms of the overall effectiveness of the prescribed load. Conversely, it tells the artillery commander how much his overall effectiveness will be reduced if one round of this type is subtracted from his allocation. Lastly, in this area of shadow prices, the upper and lower limits of the right hand side values of the constraints tell the artillery commander the range over which the shadow price of the particular right hand side value is valid.

The upper and lower limits of the objective function coefficients tell the artillery commander how much an original coefficient of the objective function can change without effecting the optimal solution given that all other values remain the same. This tells the artillery commander that even if he had weighted a particular type of ammunition more or less, as long as the value was between these upper and lower limits, then the optimal solution would not change. This helps the artillery commander evaluate his weighting of the projectiles developed in the beginning of the decision support model.

TABLE 10

DECISION VARIABLE RESULTS

AMMO TYPE	DECISION VARIABLE	OPTIMAL QUANTITY
HE (PD)	x_1	136
HE (VT)	x_2	144
HE (RAP)	x_3	-0-
ICM	x_4	240
DPICM	x_5	168
WP	x_6	16
ILLUM	x_7	-0-
HC SMOKE	x_8	16
TOTAL		720

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The decision support model developed in Chapter III and applied in Chapter IV is a simple and useful tool for assisting the future direct support artillery battery commander in the choices he will have to make concerning the appropriate ammunition mix to carry in a particular tactical situation. It provides him with a logical, step by step method, by which he can include his military experience and knowledge in the solution of this important problem.

B. RECOMMENDATIONS

Based on the research and analysis conducted in this thesis, several important recommendations for future study are listed below.

(1) That a linear programming software application be developed for the artillery battery's organic computer system.

(2) That the model developed in this thesis for the direct support artillery battery be modified and expanded for use at all levels of the Marine artillery organization. In particular, the model should be refined for use at the artillery battalion level, because this is the level at which the artillery best functions and fights.

(3) That the headquarters battery of the artillery battalion be provided with a number of either five ton or ten ton trucks for supply and ammunition hauling. This would free the trucks given up by the direct support battery and allow them to be used to haul the battery's ammunition requirements.

(4) That a study be conducted which applies the decision support model over a wide variety of scenarios, using a population of commanders to help in determining both standardized prescribed loads for different tactical situations and future preferred ammunition procurement policies. Additionally, the derived data could be used in a stockage model for the ammunition supply points and the rest of the logistics system.

APPENDIX A
ARTILLERY AMMUNITION EXPENDITURE RATES

The artillery ammunition expenditure rates listed below were taken from Reference 6, pages 12 and 13.

TABLE 11
AMMUNITION EXPENDITURE RATES

	155mm ROUNDS EXPENDED PER TUBE PER DAY
FM 101-10-1	71-203
DIVISION 86 PLANNING FACTORS	160-520
COMBAT ANALYSIS AGENCY P86 STUDY	75-95
AMMUNITION INITIATIVE TF 77 STUDY	310-520
TRADOC SCHOOLS	150-550
CSS MISSION AREA ANALYSIS	152-543
FIRE SUPPORT MISSION AREA ANALYSIS (FSMAA)	
INTENSE COMBAT	500
SUSTAINING COMBAT	325
LIGHT COMBAT	200

APPENDIX B
AMMUNITION DEFINITIONS

The definitions listed below are for ammunition allocations and other ammunition supply terms taken directly from Reference 7, page 4-7.

1. BASIC ALLOWANCE (BA-V). A specific quantity of ammunition per ammunition consuming item (howitzer) required to provide an inital distribution to Fleet Marine Force (FMF) units preparing to enter combat. Generally, the quantities representing a basic allowance are intended to reflect that quantity of ammunition which can be handled or carried within the means normally expected to be available to a given FMF unit embarking for combat operations. The FMF commander may make adjustments to the basic allowance to accommodate specific and unusual missions as well as the mode of transport to the objective area.

2. DAY OF AMMUNITION (DOA). A unit of measurement expressed as a specified number of rounds; or "items" of bulk ammunition; per weapon required for one day of combat. Normally, the DOA is used to reflect the total force requirement for one day.

3. PRESCRIBED LOAD (PL-V). Specified quantities and types of ammunition prescribed by the commander for the support of designated subordinate units. The prescribed load is not a fixed quantity and may change from day-to-day or operation-to-operation at the discretion of the commander.

a. Subordinate commanders are responsible to maintain the prescribed load on hand at all times, allowing for fluctuations above and below the prescribed quantity due to the tactical and supply situation.

b. The composition of a prescribed load for a unit may be expressed in terms of the basic allowance, plus or minus a designated number of types of rounds; it may also be expressed in days of ammunition or by a specific number of rounds or items by type. Normally, the prescribed load will be the BA-V.

c. A primary factor in determining the prescribed load is the amount of supplies which can be carried in assigned transportation.

4. REQUIRED SUPPLY RATE (RSR-V). The amount of ammunition required to initiate and sustain operations of any designated force without restriction for a specified period. The RSR-V is expressed in terms of DOA. Tactical commanders use RSR-V to state their requirements for support of planned tactical operations. It is submitted through command channels and is used by the commander to determine the available supply rate for his command. Subsequent to receipt and consolidation of all estimates for a given period of operation, the commander compares the results with his available stocks of ammunition and prevailing resupply conditions. This enables him to determine the maximum expenditure rate he can support for a given situation or time.

5. AVAILABLE SUPPLY RATE (ASR-V). The rate of consumption that can be sustained with available supplies for a given period. The ASR-V is announced or determined by each commander and is applicable within his command. The rate is expressed in terms of DOA.

6. AMMUNITION SUPPLY POINT (ASP). An activity established by logistic support agencies organic to the landing force for receipt, storage, assembly, accounting, issue and/or distribution, and limited salvage of ammunition.

7. AMMUNITION DUMP (DU-V). Temporary ammunition supply sites established for the storage of munitions. An ammunition dump will always be identified by geographical coordinates. This type activity is primarily used for temporary storage in amphibious operations during the buildup of prescribed supply levels ashore, pending establishment of normal ammunition support operations. Dumps may also be established inland as an emergency supply source, or for initial support of helicopter operations. When prescribed levels ashore have been attained, and on order of appropriate authority, dumps may become ammunition supply points for using units. Conversely, when an ASP is closed, it becomes, on order, an ammunition dump.

8. AMMUNITION DISTRIBUTION POINT (ADP). A point where ammunition supplies are distributed directly to using units. These points usually carry no stocks as the items on hand are usually drawn from ASPs for immediate issue to meet periodic or daily needs of using units. However, the physical location of ADPs may have a relative degree of performance depending on the tactical situation of the unit which it supports. They are identified by geographical coordinates.

9. DEPARTMENT OF DEFENSE AMMUNITION CODE (DODAC). A code developed by the office of the Secretary of Defense and the military departments to provide uniform, centrally assigned code numbers for generic descriptions applicable to items of supply identified as ammunition and explosives.

10. AMMUNITION LOT NUMBER. A number assigned to every component of conventional ammunition at the time of manufacture and to each complete round or fixed and semifixed ammunition at time of assembly.

APPENDIX C
RECOMMENDED 155MM PRESCRIBED LOADS

The following recommended prescribed loads were obtained from References 2 and 6.

TABLE 12
RECOMMENDED 155MM PRESCRIBED LOADS

AMMO TYPE	CENTRAL EUROPE	FSMAA	US ARMY EUROPE	FORCES COMMAND	WESTERN COMMAND
HE	8%	15%	60%	82%	47%
HE RAP	7%	10%	5%	-	-
ICM	60%	61%	6%	-	35%
SMOKE	4%	1%	16%	7%	7%
ILLUM	2%	1%	5%	3%	3%
WP	4%	-	8%	8%	8%
FASCAM	11%	5%	-	-	-
COPPER	4%	7%	-	-	-

APPENDIX D
WEIGHTING FACTOR DEVELOPMENT

The purpose of this appendix is to provide the artillery commander with a logical step by step approach to developing a subjective measure of effectiveness (MOE), which can be used as the weighting factor in the decision support model developed in Chapter III. This subjective MOE is based on the commander's experience and knowledge of the situation and uses a technique of pairwise comparisons. The following is a listing of this step by step method.

First, the commander lists the available artillery projectiles in order, from the most desirable to the least desirable, given the tactical situation, his evaluation of METT, and the maneuver commander's guidance.

TABLE 13
STEP ONE

PROJECTILE	VALUE
DPICM	
ICM	
HE (VT)	
HE (PD)	
HE (RAP)	
WP	
HC SMOKE	
ILLUM	

Next, he starts with the least desirable projectile type and assigns it a value of 10. He then moves up the listing, assigning each projectile a value which is greater than or equal to the value of the proceeding projectile as appropriate, until he reaches the top.

TABLE 14

STEP TWO

PROJECTILE	VALUE
DPICM	60
ICM	45
HE (VT)	40
HE (PD)	30
HE (RAP)	20
WP	15
HC SMOKE	15
ILLUM	10

In step three, he then compares each projectile with every other projectile and adjusts the values as necessary until they accurately reflect his opinion as to their relative desireability.

TABLE 15

STEP THREE

PROJECTILE	VALUE
DPICM	60
ICM	47
HE (VT)	40
HE (PD)	30
HE (RAP)	20
WP	17
HC SMOKE	15
ILLUM	10

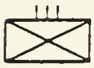
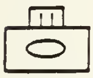
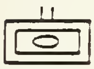
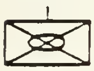
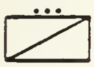
Finally, in step four he sums all the projectile values derived above and uses this total to determine each projectile's percentage value/weighting factor. This is done by dividing the projectile's value by the total, as shown in Table 16 below.

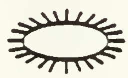
TABLE 16
STEP FOUR

PROJECTILE	VALUE	WEIGHTING FACTOR
DPICM	60	60/244 = .25
ICM	47	47/244 = .19
HE (VT)	40	40/244 = .19
HE (PD)	30	30/244 = .12
HE (RAP)	20	20/244 = .08
WP	17	17/244 = .07
HC SMOKE	15	15/244 = .06
ILLUM	10	10/244 = .04
TOTAL	244	1.00

APPENDIX E
GLOSSARY OF SYMBOLS

This glossary of symbols was taken from page 10 of Reference 1.

	Observation post, reconnaissance unit
	Enemy mechanized infantry division (called moterized rifle division in main text)
	Friendly infantry regiment
	Friendly tank-heavy, battalion-sized task force
	Enemy tank battalion
	Friendly mechanized infantry company
	Friendly reconnaissance platoon
	Enemy mechanized reconnaissance platoon
(–)	Unit with major subelement detached
(+)	Reinforced unit
	Minefield with antitank mines
	Antipersonnel mine
S	Scatterable versus hand-emplaced mines

	Light artillery battery (105-mm), towed (T)
	Medium artillery battery (155-mm) (T)
	Medium artillery battery (155-mm), self-propelled (SP)
	Heavy artillery battery (203-mm) (SP)
	Medium mortar platoon (81-mm)
	Heavy mortar platoon (120-mm)
	Strongpoint
	Position
	Reconnaissance activity
	Axis of advance
- - - -	Dashed lines mean planned action; action not yet ordered
EN	Designates enemy
—XX—	Division boundary
—|||—	Regimental boundary
—||—	Battalion boundary
	Forward line of own troops (FLOT)

APPENDIX F
DECISION SUPPORT MODEL OUTPUT

The output below represents the optimal solution to the decision support model in the case of the scenario outlined in Chapter IV. It was derived using a commercially available software package called Computer Models for Management Science, (see Reference 8, pages 29-46).

```
                    -***-  INFORMATION ENTERED  -***-

       NUMBER OF VARIABLES                    :    8
       NUMBER OF <= CONSTRAINTS               :    8
       NUMBER OF  = CONSTRAINTS               :    1
       NUMBER OF >= CONSTRAINTS               :    8

MAX  =              .12 X1 +    .19 X2 +    .08 X3 +    .19 X4 +    .25 X5
               +    .07 X6 +    .04 X7 +    .06 X8

SUBJECT TO:

       1    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        <=    248

       0    X1 +   1    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        <=    144

       0    X1 +   0    X2 +   1    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        <=    120

       0    X1 +   0    X2 +   0    X3 +   1    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        <=    240

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   1    X5
  +    0    X6 +   0    X7 +   0    X8                        <=    168

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    1    X6 +   0    X7 +   0    X8                        <=     96

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   1    X7 +   0    X8                        <=     64

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   1    X8                        <=     88

       1    X1 +   1    X2 +   1    X3 +   1    X4 +   1    X5
  +    1    X6 +   1    X7 +   1    X8                         =    720

       1    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        >=      0

       0    X1 +   1    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        >=      0

       0    X1 +   0    X2 +   1    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        >=      0

       0    X1 +   0    X2 +   0    X3 +   1    X4 +   0    X5
  +    0    X6 +   0    X7 +   0    X8                        >=      0

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   1    X5
  +    0    X6 +   0    X7 +   0    X8                        >=      0

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    1    X6 +   0    X7 +   0    X8                        >=     16

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   1    X7 +   0    X8                        >=      0

       0    X1 +   0    X2 +   0    X3 +   0    X4 +   0    X5
  +    0    X6 +   0    X7 +   1    X8                        >=     16
```

-***- RESULTS -***-

VARIABLE	VARIABLE VALUE	ORIGINAL COEFFICIENT	COEFFICIENT SENSITIVITY
X1	136	.12	0
X2	144	.19	0
X3	0	.08	0
X4	240	.19	0
X5	168	.25	0
X6	16	.07	0
X7	0	.04	0
X8	16	.06	0

CONSTRAINT NUMBER	ORIGINAL RIGHT-HAND VALUE	SLACK OR SURPLUS	SHADOW PRICE
1	248	112	0
2	144	0	.07
3	120	120	0
4	240	0	.07
5	168	0	.13
6	96	80	0
7	64	64	0
8	88	72	0
9	720	0	.12
10	0	136	0
11	0	144	0
12	0	0	.04
13	0	240	0
14	0	168	0
15	16	0	.05
16	0	0	.08
17	16	0	.06

OBJECTIVE FUNCTION VALUE: 133.36

— SENSITIVITY ANALYSIS —

OBJECTIVE FUNCTION COEFFICIENTS

VARIABLE	LOWER LIMIT	ORIGINAL COEFFICIENT	UPPER LIMIT
X1	.08	.12	.19
X2	.12	.19	NO LIMIT
X3	NO LIMIT	.08	.12
X4	.12	.19	NO LIMIT
X5	.12	.25	NO LIMIT
X6	NO LIMIT	.07	.12
X7	NO LIMIT	.04	.12
X8	NO LIMIT	.06	.12

RIGHT-HAND-SIDE VALUES

CONSTRAINT NUMBER	LOWER LIMIT	ORIGINAL VALUE	UPPER LIMIT
1	136	248	NO LIMIT
2	32	144	280
3	0	120	NO LIMIT
4	123	240	376
5	56	168	304
6	16	96	NO LIMIT
7	0	64	NO LIMIT
8	16	88	NO LIMIT
9	584	720	832
10	NO LIMIT	0	136
11	NO LIMIT	0	144
12	0	0	120
13	NO LIMIT	0	240
14	NO LIMIT	0	168
15	0	16	96
16	0	0	64
17	0	16	88

---------- E N D O F A N A L Y S I S ----------

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Determining the optimal prescribed load for the U. S. Marine Corps direct support artillery battery using linear programming.